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Technical Report 361

MARCONI AERIAL OUTFIT H-33-5500-01 EVALUATION

Comparison of this active antenna with two previously evaluated active antennas

EA Thowless

25 October 1978

Test and Evaluation: April - September 1978

Prepared for
Naval Electronic Systems Command
(ELEX 5103)

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The Marconi H-33-5500-01 antenna has significantly better noise figure and gain than either the Bayshore or DUK antenna; but, as with all active antennas, self-generated intermodulation product interference is likely where several nearby rf transmissions occur simultaneously. Despite this susceptibility, this antenna is judged to be well engineered and properly designed and optimized for integration into hf receiving systems. Because of its small size, it could serve as a backup receiving antenna for hf and lower frequencies aboard Navy ships. Relationships are presented for apparent effective height, antenna noise power output, antenna noise figure, antenna gain, operating noise figure of a complete receiving system, and intermodulation intercept points, ratios, and product levels.

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OBJECTIVE

Determine the suitability of the Marconi H-33-5500-01 antenna for use aboard CGN 42 and other Navy ships. To this end, make measurements and calculations of its 2–30 MHz performance characteristics. Compare its characteristics with those previously determined for active antennas from Bayshore Systems Corporation and Dieckmann und Klapper (DUK). Present the results of this evaluation in a form that is readily usable by either antenna or communication systems engineers.

RESULTS

1. The Marconi H-33-5500-01 antenna has significantly better noise figure and gain than either the Bayshore or the DUK antenna. A receiving system that uses it will have a satisfactory noise threshold if the receiver of the system has a low noise figure. This antenna is worth considering for use at locations where no strong interfering rf signals exist.

2. Where several hf transmitters are in simultaneous use, as is typical aboard larger Navy ships, interference from intermodulation products generated within the active Marconi H-33-5500-01 antenna (as well as the active Bayshore and DUK antennas) is likely. In susceptibility to the generation of intermodulation products by strong incident signals, the improvement of this antenna over the DUK antenna is not as great as the values of the intermodulation intercept points would seem to indicate. When a specified standard level of two fundamental incident signals is fed to each of these three active antennas, a more realistic comparison of intermodulation product levels and intermodulation ratios is obtained.

3. Measurements of apparent effective height, noise power output, and intermodulation products are necessary; but they alone do not indicate the performance quality of an active antenna. Calculations of antenna gain, antenna noise figure, and intermodulation intercept points based upon those measurements provide an indication of performance quality, but they do not indicate the quantitative performance of a complete receiving system. The noise figure of a complete receiving system includes the noise contributions and gains or losses (as appropriate) of atmospheric radio noise, the active antenna, the transmission line and its components, and the receiver. The intermodulation characteristics of various active antennas may be quantitatively compared by plotting intermodulation product level vs intermodulation ratio at a specified level of two fundamental incident signals.

4. The Marconi H-33-5500-01 is judged to be a well-engineered antenna that is properly designed and optimized for integration into hf receiving systems despite its susceptibility to intermodulation distortion from strong incident signals.

5. Because of its small size, this antenna could serve as a backup receiving antenna for hf and lower frequencies aboard Navy ships.

RECOMMENDATIONS

1. Make additional measurements on the Marconi H-33-5500-01 antenna to characterize the generation of higher than second- and third-order intermodulation distortion products.

2. To provide a baseline threshold against which intermodulation products of active antennas can be compared, investigate the magnitude of shipboard-generated intermodulation products.

3. Develop and promulgate standards of measurements and technical specifications for active antennas. This will provide information for comparing antennas developed or manufactured by various organizations and for incorporating these antennas into communications receiving systems.

CONTENTS

ILLUSTRATIONS

ANTENNA DESCRIPTION

The Marconi H-33-5500-01 active antenna consists of a rod antenna mounted atop a stout aluminum casting enclosing an rf amplifier and a power supply. Its overall height is about 2.4 m and its total weight is about 46 kg. The antenna assembly is intended for shipboard deck mounting. Although its frequency range is 10 kHz–30 MHz, the NOSC evaluation was limited to 2–30 MHz.

The amplifier consists basically of three Mullard E55L tubes in parallel in a cathode follower circuit. Output impedance is 50 ohms.

EXTENT OF EVALUATION

Tests and evaluation of antenna performance were based upon treating the Marconi antenna as a black box with appropriate input and output signals. The results of this evaluation are readily usable by either antenna engineers or communication systems engineers. Analysis of the internal design of the active antenna was not attempted. Performance of this antenna was compared with that of two other previously measured active antennas (ref 1): Bayshore UPS-191A and Dieckmann und Klapper (DUK) STA-10A24-40/0.01-30 with a 0.5 m rod antenna.

All tests, evaluations, and discussions pertain to the active antenna mounted upon an extensive, virtually lossless ground, unless otherwise indicated.

The rms values of voltage, current and power are used herein.

APPARENT EFFECTIVE HEIGHT

Figure 1 shows the measured apparent effective height, h'_e. For an active antenna, h'_e is defined as follows:

$$h'_e = 2E_L/\mathbf{E}, \tag{1}$$

where E_L is the signal voltage across the designed load resistance, for a vertical electric field, $\mathbf{E}$, along the antenna. (Assume the same polarization for $\mathbf{E}$ and the antenna.)

The output impedance of the active antenna and the designed load impedance are assumed to be conjugate. (In this case, R_L = 50 ohms.) Then

1. NOSC TN 194, Evaluation of Two Active Antennas, by EA Thowless, 14 July 1977. NOSC TNs are informal documents intended chiefly for internal use.

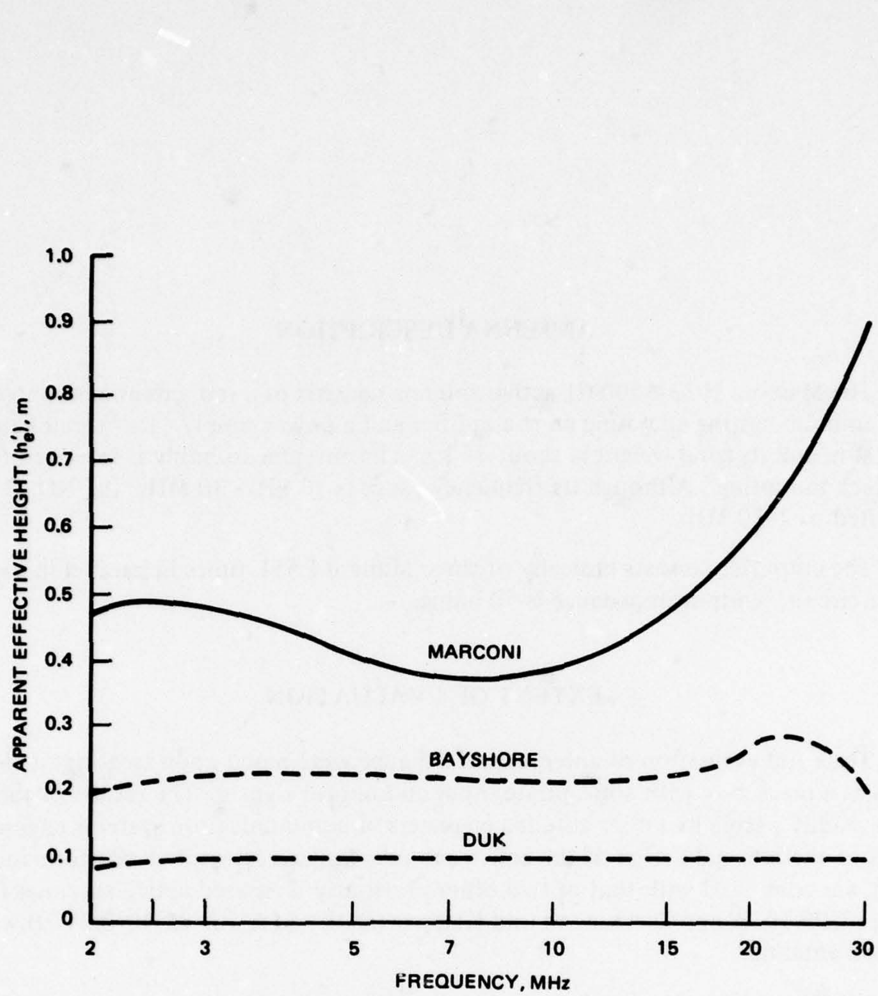


Figure 1. Measured apparent effective height vs frequency.

$$h_e' = E_{OC}/\mathbf{E} \text{ or } E_{OC} = \mathbf{E}\, h_e' \quad , \tag{2}$$

where E_{OC} is the antenna open-circuit output signal voltage. Equation (2) is similar to the equation that holds for passive antennas except for the distinction of "apparent effective height." The distinction is made because the apparent effective height is a function of more than merely the physical length of the vertical element, as is the case for a passive vertical antenna. For active antennas of the type being evaluated, the apparent effective height is a function of rod length, ratio of shunt capacitance to antenna (rod) capacitance, amplifier gain, and any impedance transformation between the rod and the input to the amplifier.

The apparent effective height of an active antenna was determined by creating a known incident surface wave field at the antenna and measuring the output signal voltage. The field was generated by exciting an electrically short vertical monopole. Both the monopole and the active antenna were underlaid by an extensive wire mesh ground plane. With the height of the monopole known along with the current at its base (by measurement) and the distance from the monopole to the active antenna, the vertically polarized surface wave field strength incident upon the active antenna was calculated by the following expression:

$$\mathbf{E}_\theta \text{ (in V/m)} = 30\,\beta^2\,IL\left[\frac{1}{(\beta r)^2} + j\left(\frac{1}{\beta r} - \frac{1}{(\beta r)^3}\right)\right], \tag{3}$$

where

$\beta = 2\pi/\lambda$

I = antenna base current (A)

L = overall length of radiating short monopole (m)

The calculated field strengths were verified by measurements made with a field strength meter. This modification of the equation for the rms *electric-field component* $\mathbf{E}_\theta$ *of a short* dipole, from Jasik (ref 2), is also applicable for a short monopole over perfect ground, with a linear current distribution.

An elevated location of the antenna above any nonresonant ground platform will alter the apparent effective height by a factor which is a function of the electrical height of the supporting structure and of the location of the active antenna on that structure. Because these active antennas are basically voltage probes, raising the antenna above a nonresonant ground platform (such as onto a metallic tower or mast) will alter the pickup response of the antenna – manifested as a change in h_e'. This change in h_e' due to elevated mounting, not given a particular name or symbol, is indicated as a multiplying factor.

The changes in h_e' when the Marconi antenna was located upon a metallic tower were not measured. Appendix A discusses this change in h_e' in more detail, with graphical data for the Bayshore and DUK antennas.

EFFECTIVE AREA

The effective area (A_e) of any antenna is the ratio of P_L, the maximum available power deliverable to a matched load impedance, to P_D, the incident power density, assuming matched polarization:

$$A_e \text{ (in m}^2\text{)} = P_L/P_D\ . \tag{4}$$

Maximum available power

$$P_L = E_L^2/R_L$$

$$= E_{oc}^2/4\,R_L\ ,$$

where

E_L = voltage across the load

2. Antenna Engineering Handbook, 1st edition, p 2-2, HJ Jasik, ed, McGraw-Hill, 1961

R_L = load resistance (antenna output resistance)

E_{oc} = open-circuit output voltage of antenna.

Power density

$$P_D = \mathbf{E}^2/120\pi$$

where

$\mathbf{E}$ = field along the antenna

120π = impedance cf free space.

Thus

$$A_e \text{ (in m}^2) = \frac{E_{oc}{}^2/4\,R_L}{\mathbf{E}^2/120\pi}$$

$$= \frac{30\pi h_e{}^2}{R_L} \quad , \tag{5}$$

where

$$h_e = E_{oc}/\mathbf{E} \quad .$$

Equation (5) is applicable to all antennas. The effective area of active antennas being evaluated, where h_e is h'_e and R_L = 50 ohms, is as follows:

$$A_{e_{aa}} \text{ (in m}^2) = \frac{30\pi\, h_e'^2}{R_L} \tag{6}$$

$$= 1.885\, h_e'^{\,2} \quad .$$

The effective area of an electrically short monopole over perfect ground is

$$A_{e_m} \text{ (in m}^2) = D\lambda^2/16\pi \quad , \tag{7}$$

where D is monopole directivity (= 3).

NOISE OUTPUT

Figure 2 shows measured output noise power. With no incident external noise or signal, the noise output was found to be 6.7 dB above thermal noise at 2 MHz, decreasing to 6 dB above thermal noise from 3 to 30 MHz.

The noise measurements were performed with the antenna in a large screen room. Noise output from a standard noise source of known noise power output and a matched attenuator was made equal to the noise output of the active antenna.

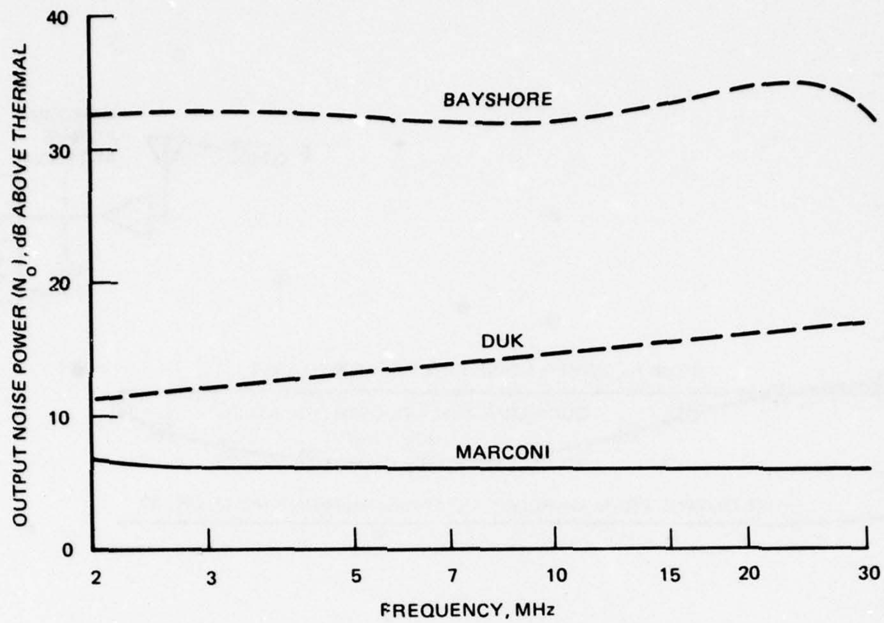


Figure 2. Measured output noise power vs frequency.

NOISE LEVELS AT ANTENNA OUTPUT

The relationships of the principal noise contributors of a simple receiving system employing the Marconi antenna are shown in figure 3. The reference plane for the noise values is at the interface between the active antenna and a receiver with a 16 dB noise figure. The quasiminimum atmospheric radio noise level (ref 3) is also transformed to the receiver input.

Figure 3 shows that a receiving system using a receiver with a 10 dB noise figure would be predominantly atmospheric noise limited.

16 dB was an arbitrary choice for receiver noise figure. It represents a receiver with a sensitivity of 0.5 μV measured at the input terminals or 1V open-circuit voltage from a 50 Ω antenna, which would yield a signal-plus-noise to noise ratio of 10 dB with a 3 kHz bandwidth.

Quasiminimum atmospheric noise is a representation of typically low atmospheric noise conditions (ref 3, 4) that may be used as design criteria for noise considerations of a receiving system in the hf range and for the design of any rf components of that system.

---

3. NOSC Technical Report NELC TR 1786, TRED Hf Communication System Analysis, by WM Chase and CW Tirrel, 24 September 1971
4. ECAC-CR-76-074, ECAC Analysis Report to ITEMA Program in FY-7T, by D Baran and SJ Caprio, October 1976

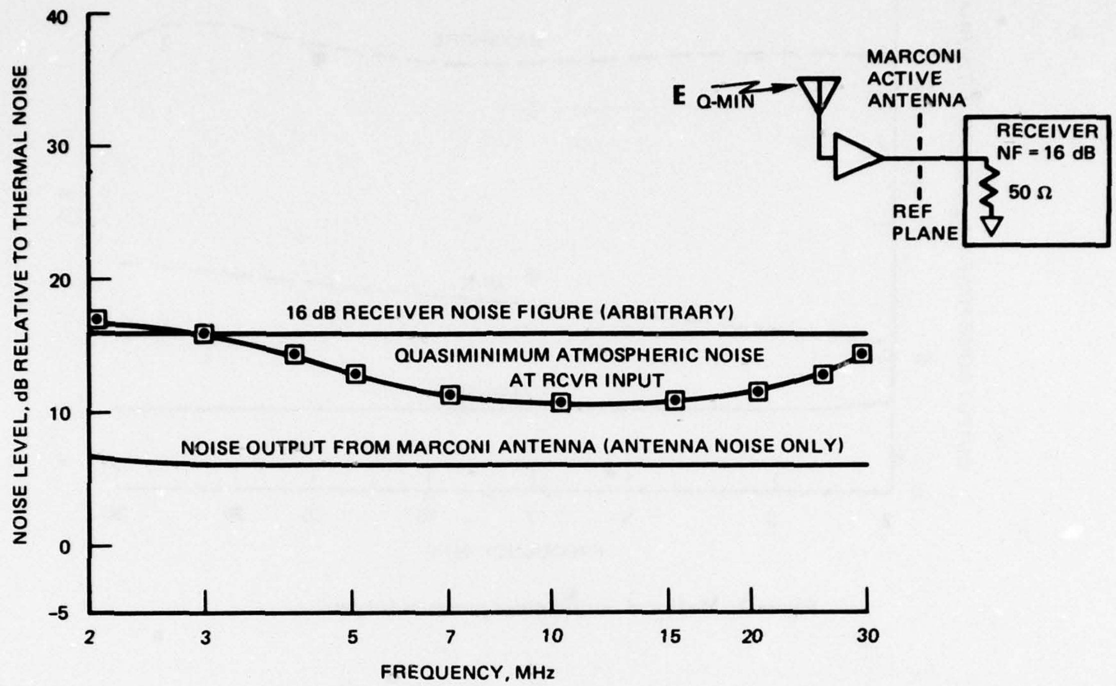


Figure 3. Noise levels at the output of the Marconi antenna.

Quasiminimum atmospheric noise, like the atmospheric radio noise portrayed in CCIR Report 322 (ref 5), represents the maximum available noise power from a lossless short vertical antenna. The level of quasiminimum atmospheric noise, P_Q, is expressed mathematically as follows:

$$P_Q \text{ (in dB above } kT_0B) = 60.3 - 27.3 \log_{10} f \ , \tag{8}$$

where f is in MHz.

Figures 4 and 5, reproduced from NOSC TN 194 (ref 1), show comparable curves for the Bayshore and DUK active antennas each in a simple receiving system. Figure 5 shows the receiving system to be severely limited by noise from the Bayshore antenna. Figure 4 shows the receiving system to be equipment noise limited. In fact, quasiminimum noise transformed to the DUK antenna output is below thermal noise for frequencies above about 7 MHz.

5. CCIR Report 322, World Distribution and Characteristics of Atmospheric Radio Noise, 1963

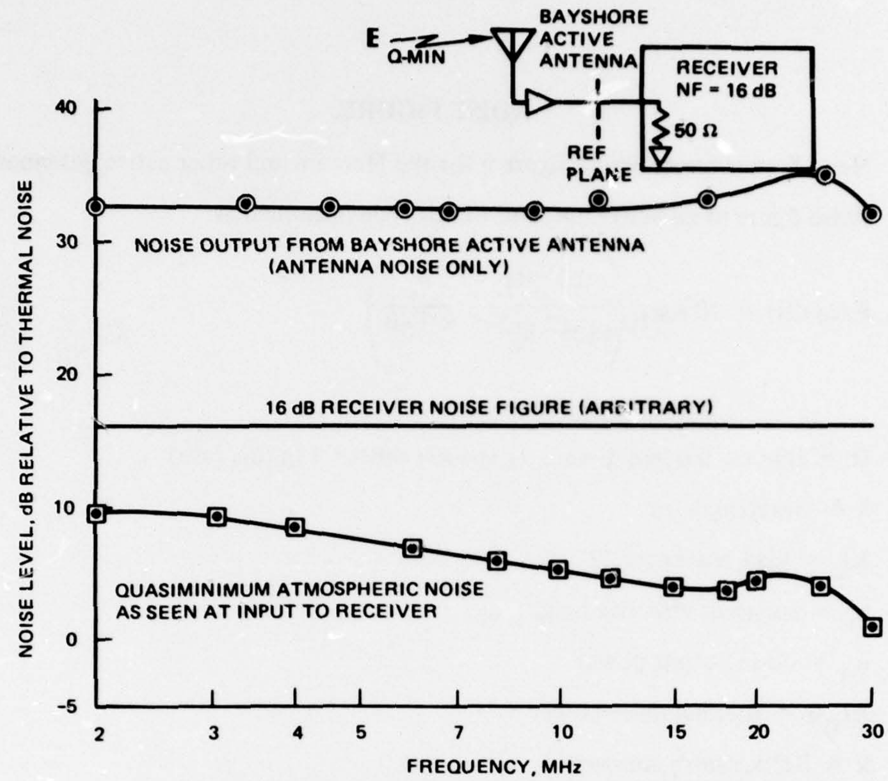


Figure 4. Noise levels at the 2-30 MHz output of the Bayshore UPS-191 active antenna.

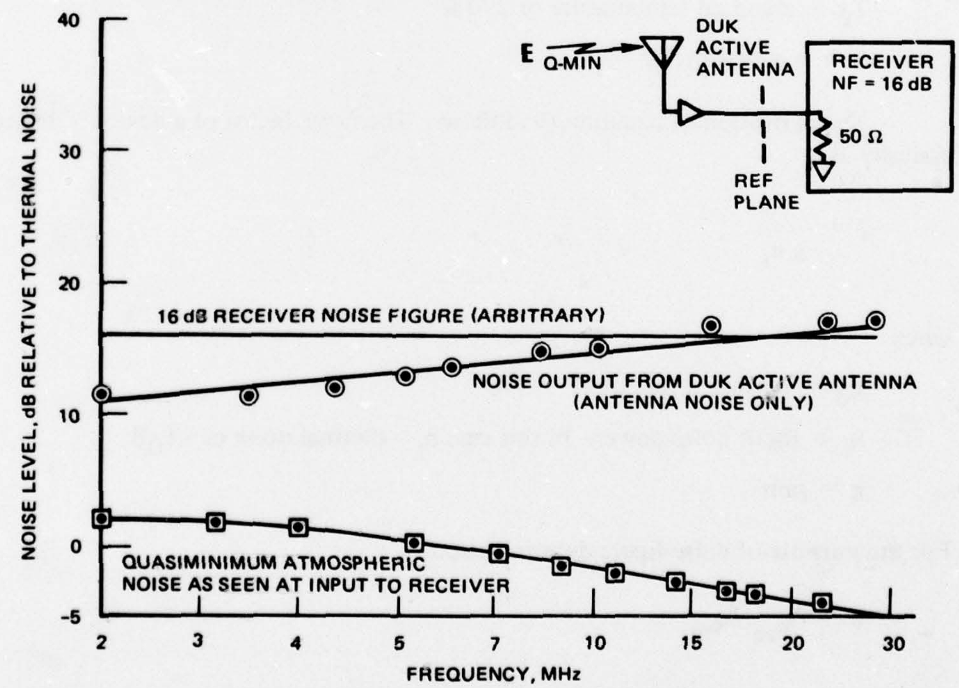


Figure 5. Noise levels at the output of the DUK active antenna.

NOISE FIGURE

Noise figures are shown in figure 6 for the Marconi and other active antennas.

Noise figure of an active antenna of this type is defined as

$$F\ (\text{in dB}) = 10 \log_{10}\left(\frac{D\lambda^2 R_L}{480\pi^2 h_e'^2} \cdot \frac{n_o}{k\,T_0 B}\right) , \tag{9}$$

where

D = antenna pattern directivity (power ratio = 3 in this case)

λ = wavelength, m

R_L = load resistance, Ω

h_e' = apparent effective height, m

n_o = noise output power

kT_0B = thermal noise power

k = Boltzmann's constant
= 3.98×10^{-21} W

T_0 = standard temperature of 290 K

B = bandwidth, Hz

The derivation of equation (9) follows. The noise factor of a device is defined basically as

$$f = \frac{n_o}{g\,n_i} , \tag{10}$$

where

n_o = output noise power

n_i = input noise power. In this case n_i = thermal noise or kT_0B

g = gain

For the purpose of noise figure determination,

$$g = A_{e_{aa}} / A_{e_m} , \tag{11}$$

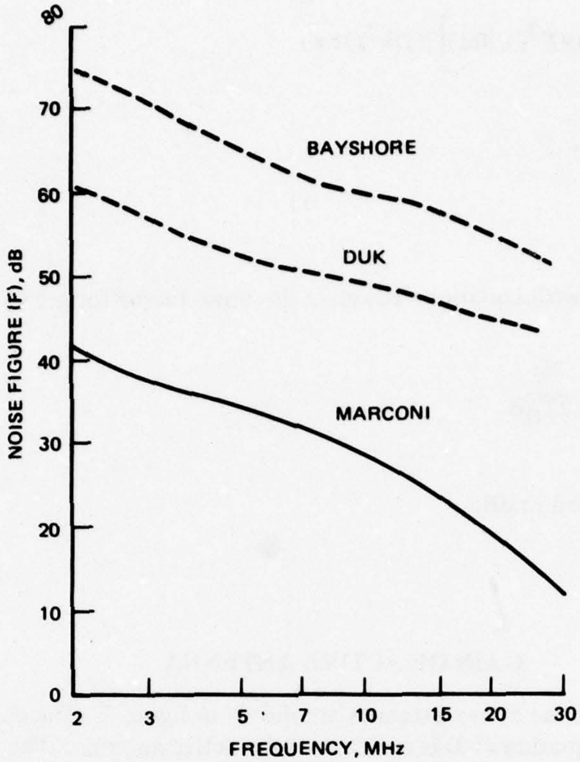


Figure 6. Noise figure vs frequency (calculated from measurements).

where

$A_{e_{aa}}$ = maximum effective aperture of the active antenna

= P_L/P_D from equation (4) (applicable to any antenna)

A_{e_m} = maximum effective aperture of a short vertical monopole

= $D\lambda^2/16\pi$ (from equation (7))

The rationale for using A_{e_m} as a gain reference in the definition of noise figure for active antennas is discussed in appendix B. Thus equation (11) becomes

$$g = \frac{A_{e_{aa}}}{A_{e_m}}$$

$$= \frac{P_L/P_D}{D\lambda^2/16\pi}$$

$$= \left[(E_{oc}^2 /4 R_L)/(E^2/120\pi)\right]/(D\lambda^2/16\pi)$$

$$= \frac{480\pi^2 h_e'^2}{D\lambda^2 R_L} \quad , \tag{12}$$

where $h_e' = E_{oc}/E$.

Combining equation (12) with equation (10) gives the noise factor for active antennas:

$$f = \frac{D\lambda^2 R_L}{480\pi^2 h_e'^2} \cdot \frac{n_o}{kT_0 B} \quad . \tag{13}$$

The noise figure is expressed in dB:

$$F = 10 \log_{10} f \quad . \tag{14}$$

GAIN OF ACTIVE ANTENNA

Calculated gains of the active antennas are shown in figure 7. The gain, g, (12) as used in the noise factor equation (10) is not that of the active antenna. The gain reference for g is the gain of "a short vertical antenna over a perfectly conducting ground-plane," which is used for defining the atmospheric noise factors of CCIR 322 as well as for quasiminimum atmospheric noise.

A valid expression for active antenna gain, g_c, is obtained by letting D = 1 in equation (12). Thus, the expression for the gain of an active antenna relative to an isotropic antenna is

$$g_c = \frac{480}{R_L}\left(\frac{\pi h_e'}{\lambda}\right)^2 \quad . \tag{15}$$

Since the designed load impedance, R_L, of these active antennas is 50 Ω,

$$g_c = 94.75\left(\frac{h_e'}{\lambda}\right)^2 \quad . \tag{16}$$

Expressing active antenna gain in dB,

$$G_c = 10 \log g_c \tag{17}$$

$$= 19.77 + 20 \log (h_e'/\lambda) \text{ dBi} \quad . \tag{18}$$

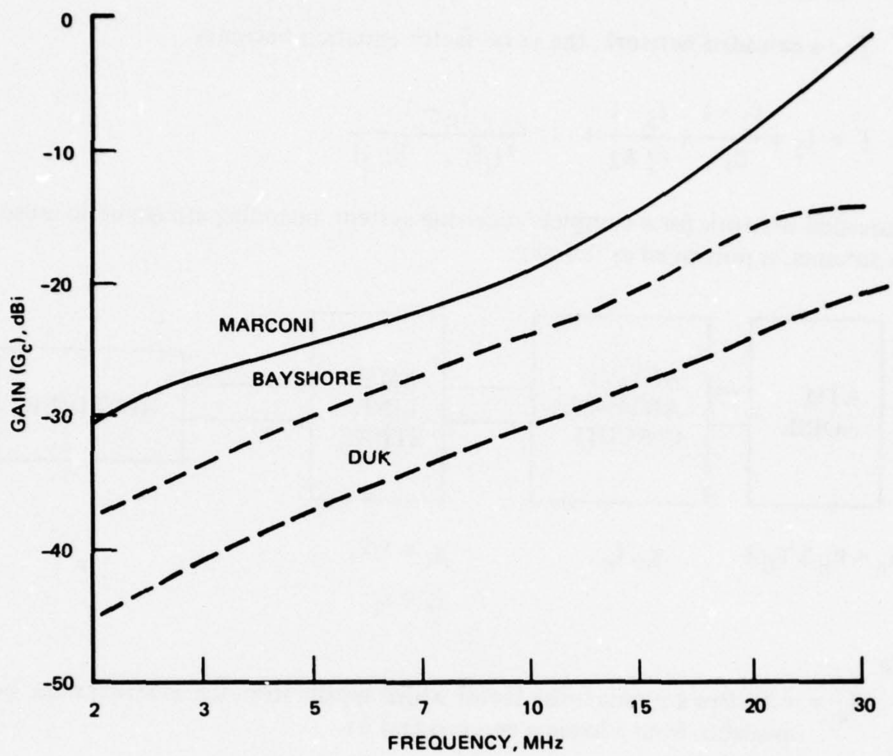


Figure 7. Calculated antenna gain vs frequency.

Gain and effective area are related by comparing equations (5) and (15):

$$A_{e_{aa}} = 30\pi \, h_e'^2 / R_L$$

$$g_c = \frac{480}{R_L} \left(\frac{\pi \, h_e'}{\lambda} \right)^2 .$$

Solving for h_e' in each equation and equating the results,

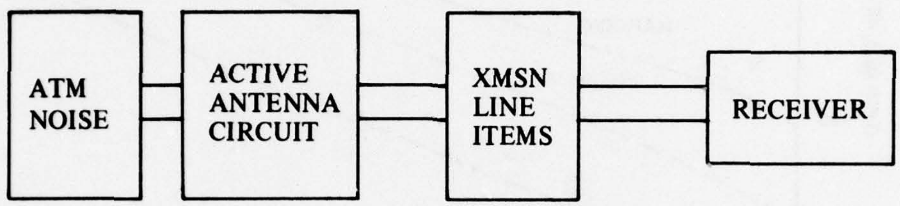
$$A_{e_{aa}} = \frac{g_c \, \lambda^2}{16\pi} . \tag{19}$$

OPERATING NOISE FIGURE OF A COMPLETE RECEIVING SYSTEM

For a cascaded network, the noise factor equation becomes

$$f = f_1 + \frac{f_2 - 1}{g_1} + \frac{f_3 - 1}{g_1 \, g_2} + \cdots \frac{f_n - 1}{g_1 \, g_2 \cdots g_{n-1}} \; . \tag{20}$$

The cascaded network for a complete receiving system, including atmospheric noise and an active antenna, is portrayed as follows:



$f_a = P_n/kT_0B$ $\qquad g_c, f_c \qquad g_t = 1/\ell_t$, $f_t = \ell_t \qquad f_r$

where

f_a = effective antenna noise factor *which results from the external noise power* available from a lossless antenna (ref 3)

P_n = noise power available from an equivalent lossless antenna

kT_0B = thermal noise power (-204 dBW, 1 Hz bandwidth)

g_c = gain of active antenna

f_c = noise factor of active antenna

ℓ_t = loss associated with transmission line and associated passive components ($= \ell/g_t$)

f_r = receiver noise factor

The noise factor expression for a complete receiving system (ref 6) is (after eq 20)

$$f = f_a + f_c - 1 + \frac{\ell_t f_r - 1}{g_c} \; , \tag{21}$$

and the noise figure, expressed in dB, becomes

$$F = 10 \log_{10} f \; . \tag{22}$$

---

6. NBS Technical Note 102, Performance Predictions for Single Tropospheric Communication Links and for Several Links in Tandem, by AP Barsis, KA Norton, PL Rice, and PH Elder, August 1961

Figure 8 shows the noise figure for a complete receiving system for each of the three active antennas. Quasiminimum atmospheric noise is used for P_n, and the receiver noise figure was arbitrarily assumed to be 16 dB. Figure 8 shows that a receiving system with a Marconi antenna comes close to being limited by atmospheric noise. Figure 3 shows that the receiving system would be mostly noise limited if a receiver with a noise figure of 10 dB or less were to be used.

DISTORTION PRODUCTS AND INTERCEPT POINTS

Figure 9 shows the slopes of the measured distortion products and the resultant intermodulation intercept points for the Marconi antenna for two fundamental tones. Table 1 lists the intercept points for the three antennas measured to date.

Table 1. Intermodulation intercept points.

Antenna	2nd order $\left[\overset{2}{I}\right]$, dBm	3rd order $\left[\overset{3}{I}\right]$, dBm
Bayshore (1)	+36	+29
DUK (1)	+43.5	+38
Marconi (2)	+82	+60

Notes: (1) Fundamental frequencies: 2.1 and 3.0 MHz
(2) Fundamental frequencies: 5.5 and 8.0 MHz

Unfortunately, the frequencies used for the Marconi antenna were not the same as those used for the Bayshore and DUK antennas. However, the intermodulation intercept points are not expected to change appreciably for different frequencies.

A comprehensive way of comparing intermodulation characteristics of the three antennas is by plotting the intermodulation ratios, $\overset{m}{R}$, and the corresponding intermodulation product levels, $\overset{m}{P}$, that occur for a specified standard incident field strength of the two fundamental signals. This is shown in figure 10.

The standard incident field strength of the fundamental signals is assumed here to be 1.0 V/m.

The intermodulation ratio, $\overset{m}{R}$, is the level (in dB) of the generated intermodulation product below the fundamental signals at the output of the antenna. This ratio should be as great as possible. It is expressed as follows:

$$\overset{m}{R}\ (\text{in dB}) = (m-1)\left(\overset{m}{I} - S\right) , \tag{23}$$

where

m = order of the intermodulation product

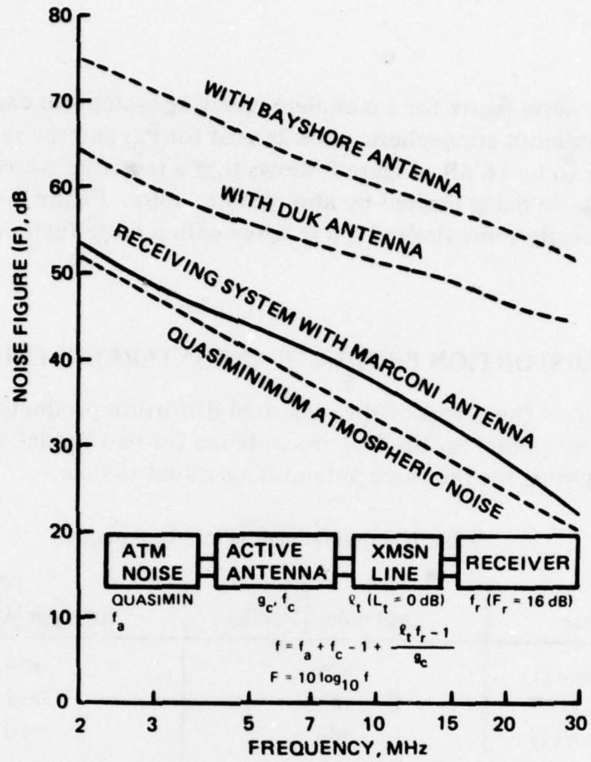


Figure 8. Calculated operating noise figure (F) of complete receiving system.

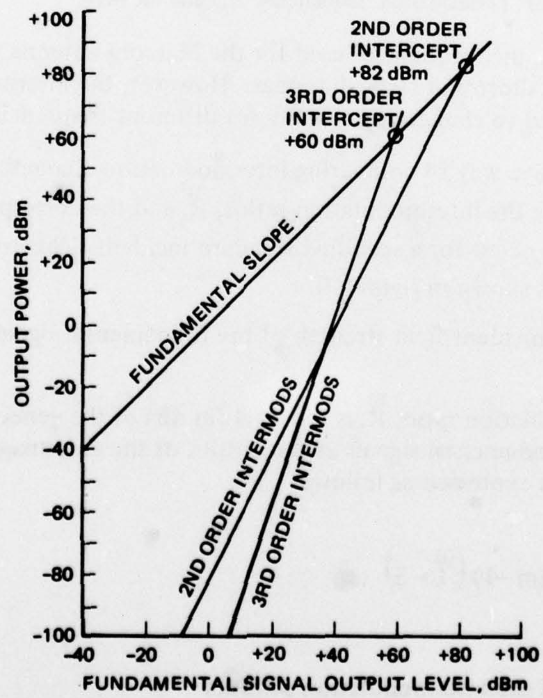


Figure 9. Measured distortion products and intercept points for Marconi Aerial Outfit H-33-5500-01.

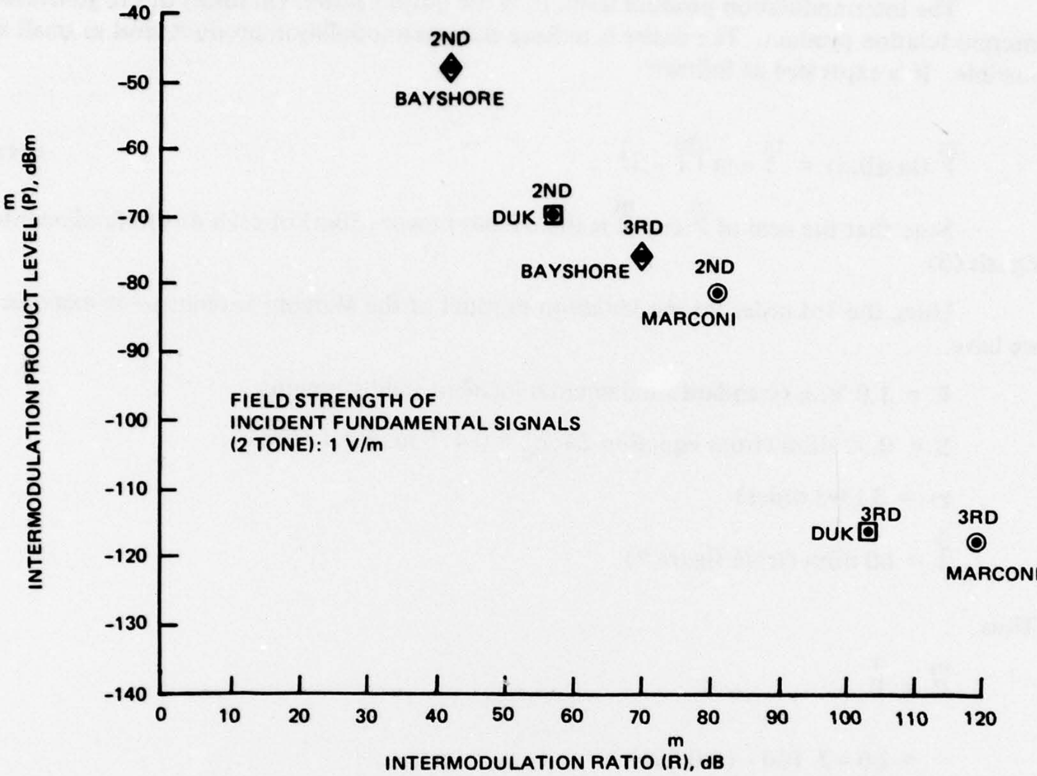


Figure 10. Comparison of intermodulation characteristics of three active antennas (calculated from measurements).

$\overset{m}{I}$ = intercept point of the m^{th} order, dBm

S = output signal level of the fundamental tones, dBm

S, dependent upon the incident field strength and h_e' of the antenna, is calculated as follows:

$$S\,(\text{in dBm}) = 30 + 10 \log_{10} \frac{(h_e' \, E)^2}{4R_L}\,, \tag{24}$$

where

h_e' = apparent effective height, m

E = incident field strength of the fundamental, V/m

R_L = load resistance (50 Ω for these antennas)

The intermodulation product level, $\overset{m}{P}$, is the output power (in dBm) of the generated intermodulation product. The desire is to have the intermodulation product level as small as possible. It is expressed as follows:

$$\overset{m}{P}\ (\text{in dBm}) = \overset{m}{I} - m\left(\overset{m}{I} - S\right) \ . \tag{25}$$

Note that the sum of $\overset{m}{P}$ and $\overset{m}{R}$ is the output power (dBm) of each of the fundamental signals (S).

Using the 3rd order intermodulation product of the Marconi antenna as an example, we have

$\mathbf{E}$ = 1.0 V/m (standard fundamental incident field strength)

S = 0.52 dBm (from equation 24; $h_e' = 0.475$ m, $\mathbf{E} = 1$ V/m)

m = 3 (3rd order)

$\overset{3}{I}$ = 60 dBm (from figure 9)

Thus

$$\overset{m}{P} = \overset{3}{P}$$

$$= 60 - 3\ [60 - (+0.52)]$$

$$= -118.43 \text{ dBm}$$

$$\overset{m}{R} = \overset{3}{R}$$

$$= (3 - 1)\ [60 - (+0.52)]$$

$$= +118.95 \text{ dB}$$

$$S = -118.43 \text{ dBm} + 118.95 \text{ dB} = +0.52 \text{ dBm}$$

The intermodulation characteristics of the three active antennas are also summarized in table 2.

Table 2. Intermodulation characteristics for three active antennas (for 1 V/m field strength of incident fundamental signals).

Antenna	$\overset{2}{R}$, dB	$\overset{2}{P}$, dBm	$\overset{3}{R}$, dB	$\overset{3}{P}$, dBm
Bayshore	42.2	-48.3	70.3	-76.5
DUK	57.0	-70.4	102.9	-116.4
Marconi	81.5	-81.0	119.0	-118.4

The amount of improvement of the Marconi antenna over either the Bayshore or the DUK to the susceptibility to generation of intermodulation products by strong incident signals is not as great as the values of the intermodulation intercept points ($\overset{2}{I}$ and $\overset{3}{I}$ of table 1) would seem to indicate. Using the third-order intermods as an example, Marconi $\overset{3}{I}$ shows 22 dB improvement over DUK $\overset{3}{I}$ (60–38). Yet Marconi $\overset{3}{P}$ is only 2 dB lower than DUK $\overset{3}{P}$ [-118.4 - (-116.4)], and Marconi $\overset{3}{R}$ is but 16 dB better than DUK $\overset{3}{R}$ (119.0 - 102.9).

SIGNAL COMPRESSION

Signal compression of the Marconi antenna was measured by observing the decrease by 1 dB of a nominal -70 dBm output, 12 MHz signal as a 10 MHz interfering cw signal was increased in amplitude. This 1 dB compression occurred at a 10 MHz interfering signal level of 9.2 V at the 50 Ω output.

Because signal compression measurements for the Marconi antenna were not done the same way as for the Bayshore and DUK antennas, exact comparisons are not valid. The 1 dB signal compression values for the Bayshore and DUK antennas were obtained by observing where the respective input-output curves rolled off 1 dB, measured using a 3 MHz cw signal.

These test method differences having been pointed out, the results are summarized in table 3.

Table 3. 1 dB signal compression of active antennas.

Antenna	1 dB Compression Level Measured at Output (in 50 Ω System), dBm	Equivalent Incident Field Intensity, V/m	Notes
Bayshore	12.3 (E_L = 0.92 V)	9.3	(1)
DUK	22.7 (E_L = 3.05 V)	72	(1)
Marconi	32.3 (E_L = 9.2 V)	26.8	(2)

Notes: (1) 1 dB roll-off of input-output curve (3 MHz cw signal)
(2) 1 dB decrease of low-level, 12 MHz cw signal, caused by a high-level 10 MHz output signal (9.2 V)

CONCLUSIONS*

1. The Marconi H-33-5500-01 antenna has significantly better noise figure and gain than either the Bayshore or the DUK antenna. A receiving system that uses it will have a satisfactory noise threshold if the receiver of the system has a low noise figure. This antenna is worth considering for use at locations where no strong interfering rf signals exist.

2. Where several hf transmitters are in simultaneous use, as is typical aboard larger Navy ships, interference from intermodulation products generated within the active Marconi H-33-5500-01 antenna (as well as the active Bayshore and DUK antennas) is likely. In susceptibility to the generation of intermodulation products by strong incident signals, the improvement of this antenna over the DUK antenna is not as great as the values of the intermodulation intercept points would seem to indicate. When a specified standard level of two fundamental incident signals is fed to each of these three active antennas, a more realistic comparison of intermodulation product levels and intermodulation ratios is obtained.

3. Measurements of apparent effective height, noise power output, and intermodulation products are necessary; but they alone do not indicate the performance quality of an active antenna. Calculations of antenna gain, antenna noise figure, and intermodulation intercept points based upon those measurements provide an indication of performance quality, but they do not indicate the quantitative performance of a complete receiving system. The noise figure of a complete receiving system includes the noise contributions and gains or losses (as appropriate) of atmospheric radio noise, the active antenna, the transmission line and its components, and the receiver. The intermodulation characteristics of various active antennas may be quantitatively compared by plotting intermodulation product level vs intermodulation ratio at a specified level of two fundamental incident signals.

4. The Marconi H-33-5500-01 is judged to be a well-engineered antenna that is properly designed and optimized for integration into hf receiving systems despite its susceptibility to intermodulation distortion from strong incident signals.

5. Because of its small size, this antenna could serve as a backup receiving antenna for hf and lower frequencies aboard Navy ships.

RECOMMENDATIONS

1. Make additional measurements on the Marconi H-33-5500-01 antenna to characterize the generation of higher than second- and third-order intermodulation distortion products.

2. To provide a baseline threshold against which intermodulation products of active antennas can be compared, investigate the magnitude of shipboard-generated intermodulation products.

3. Develop and promulgate standards of measurements and technical specifications for active antennas. This will provide information for comparing antennas developed or manufactured by various organizations and for incorporating these antennas into communications receiving systems.

*These apply to 2–30 MHz only.

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APPENDIX A: ELEVATED MOUNTING ON A METALLIC TOWER

An active antenna of the type undergoing evaluation is basically an rf voltage probe that samples the electric field strength at the location of the antenna, where the antenna is mounted on any metallic structure. The voltage distribution in a metallic tower is a function of the physical geometry of the tower and its electrical length. Thus placement of the antenna high on a metallic tower or mast will have an altered pickup response, manifested as a change in h_e'. (h_e' is defined and measured with the active antenna located on a flat, extensive, nonresonant, virtually lossless ground plane.) This unnamed change of h_e' due to elevated mounting is indicated as a multiplying factor applied to h_e' (Xh_e'). The multiplying factor may be greater or less than unity, depending upon frequency.

The Marconi antenna was not measured while mounted on a metallic tower since it is intended for deck mounting. However, for completeness of this report, figures A1 and A2 show the changes in h_e' (Xh_e'), parametric in frequency, as a function of tower height for the Bayshore and the DUK antenna, respectively, mounted atop the tower. Figure A1 shows the results of measurements at NOSC. Figure A2 is from technical information provided by DUK.

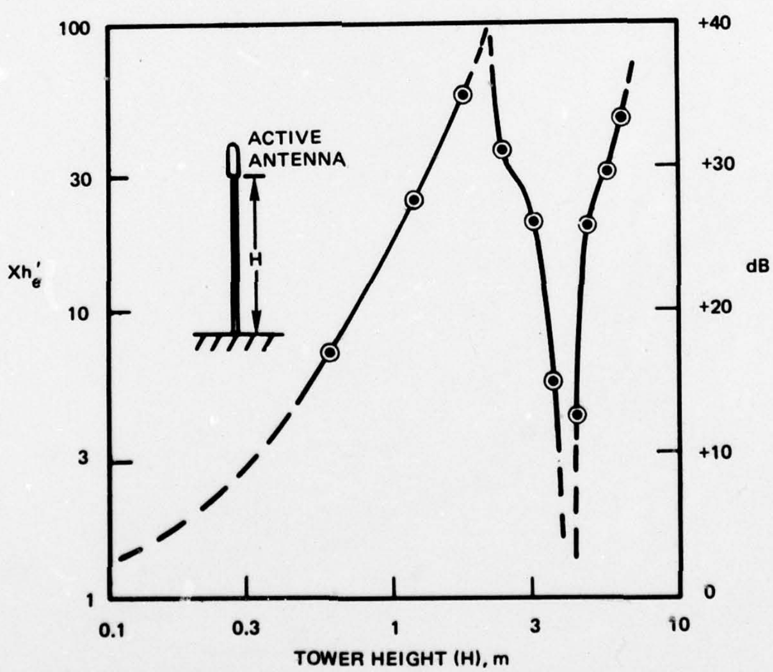

Figure A1. Measured increase in effective height vs tower height, for Bayshore UPS-191. Aluminum tower diameter about 35 mm; frequency 30 MHz.

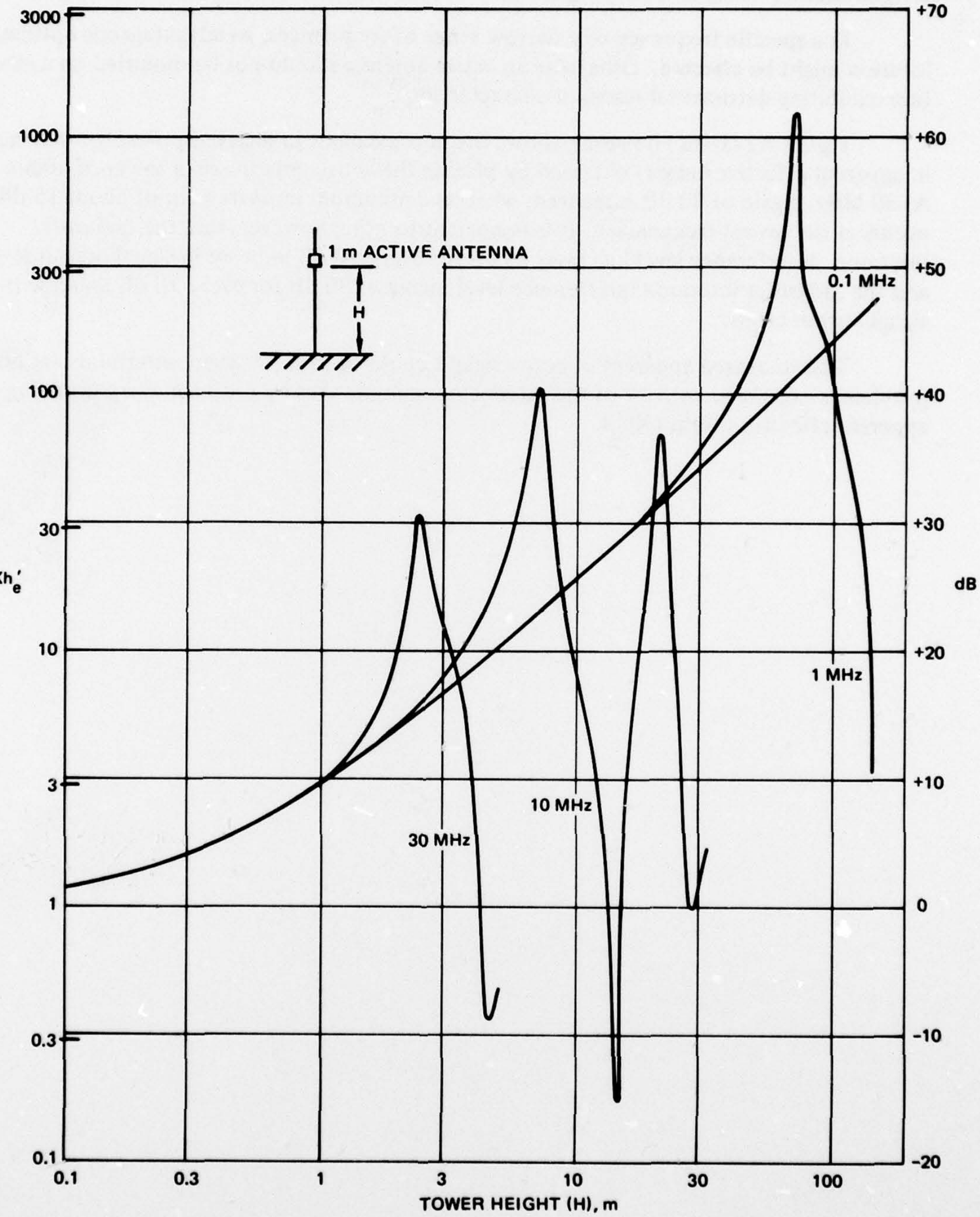

Figure A2. Increase in effective height (Xh_e') vs tower height, for DUK 1 m active antenna. (Redrawn from DUK technical data sheet DUK 452.5.75)

Note the similar, though not identical, behavior at 30 MHz. The upper peaks of the curves correspond to tower heights of odd quarter wavelengths. The lower peaks correspond to integral half-wavelength tower heights.

In a specific frequency or a narrow range of frequencies, an advantageous optimum location might be selected. Otherwise an active antenna should not be mounted on a structure exhibiting detrimental resonant characteristics.

Figure A2 (DUK) however, shows the improvement in received power (or increase in apparent effective height) obtained by placing the active antenna on a tower of about 2.5 m. At 30 MHz, a gain of 30 dB is realized, whereas a minimum improvement of about 15 dB occurs at the lowest frequencies. It is important to note, however, that the 2nd-order intermod interference level increases 20 dB for every 10 dB increase in signal output levels, and the 3rd-order intermod interference level increases 30 dB for every 10 dB increase in signal output levels.

This increased apparent effective height could be utilized where intermods are no problem, since the sensitivity of the active antenna improves by 6 dB for every doubling of apparent effective height (Xh_e').

APPENDIX B: GAIN DEFINITION FOR THE NOISE FACTOR EQUATION

The following definition is used here for noise factor:

$$f = n_o / g\, n_i \quad , \tag{B1}$$

where

n_o = output noise power

n_i = input noise power (in this case $n_i = kT_0B$)

g = gain

Under discussion is the definition for gain, g, when used in this circumstance for the noise factor of an active antenna. Gain is defined as the ratio of the effective area of an active antenna, $A_{e_{aa}}$ to the effective area of a short vertical lossless monopole A_{e_m}:

$$g = A_{e_{aa}} / A_{e_m} \quad . \tag{B2}$$

This short vertical lossless monopole is identical to the "short vertical antenna over a perfectly conducting ground-plane" used for atmospheric noise in CCIR Report 322 and for quasiminimum atmospheric noise.

The definition of g is not rigorous. Its validity will be shown by calculating noise figure, F (= 10 log f), by two different methods and obtaining identical results.

METHOD 1

$$g = A_{e_{aa}} / A_{e_m}$$

$$= \frac{P_L / P_D}{D\lambda^2 / 16\pi} \quad , \tag{B3}$$

where

$A_{e_{aa}} = P_L / P_D$

$A_{e_m} = D\lambda^2 / 16\pi$

P_L = maximum available power deliverable to matched load resistance R_L

P_D = power density incident upon antenna (matched polarization assumed)

D = directivity of monopole (= 3)

λ = wavelength of frequency of interest.

Further,

$$P_L = E_{oc}^2/4\, R_L \qquad \text{(B4)}$$

$$P_D = \mathbf{E}^2/120\pi \ , \qquad \text{(B5)}$$

where

E_{oc} = open-circuit output voltage of active antenna

R_L = designed load impedance (= 50 Ω for the antennas being evaluated)

$\mathbf{E}$ = field strength along the antenna

120π = impedance of free space

Combining equations (B4) and (B5) into (B3):

$$g = \frac{480\,\pi^2\, h_e'^2}{D\, R_L\, \lambda^2} \ , \qquad \text{(B6)}$$

where $h_e' = E_{oc}/\mathbf{E}$.

Combining equations (B6) and (B1) yields the following expression for the active antenna noise factor:

$$f = \frac{D\,\lambda^2\, R_L}{480\,\pi\, h_e'^2} \cdot \frac{n_o}{k\,T_0 B} \ .$$

Expressed in dB, the noise figure

$F = 10 \log f.$

The following is a numerical example of the use of method 1 for obtaining the noise figure of the Marconi antenna at 10 MHz.

D = 3 (directivity of monopole)

λ = 30 m (10 MHz frequency arbitrarily chosen)

R_L = 50 Ω (designed load resistance)

n_o/kT_0B = 6 dB above kT_0B (from figure 2)
= 3.98

h_e' = 0.39 m (from figure 1)

Thus

$$f = \frac{3 \times 30^2 \times 50}{480\,\pi^2 \times 0.39^2} \times 3.98$$

$$= 746$$

$F = 28.7$ dB (also see fig 6 in the text)

METHOD 2

This method for determining F is based upon reasoning about noise levels at the output of a Marconi antenna as well as knowledge of the level of atmospheric noise.

Three noise contributions are seen at the output of the active antenna (and input of the receiver): (1) quasiminimum atmospheric noise at the output of the active antenna as transformed by the active antenna, (2) self-generated noise from only the active antenna, and (3) the noise level equivalent of the receiver noise figure.

The ratio of the self-generated output noise power of the active antenna (N_o) to the quasiminimum atmospheric noise power as perceived at the output of the active antenna (N_a) can be obtained from figure 3 of the text. At 10 MHz,

N_o = 6 dB above kT_0B

N_a = 10.3 dB above kT_0B .

Quasiminimum atmospheric noise, P_Q, relative to thermal noise is known (or can be calculated). Thus it follows that the noise figure of the active antenna is the sum of the amount that the noise of the active antenna is above (or below) atmospheric noise, plus the amount that atmospheric noise is above thermal noise.

$F = (N_o - N_a) + P_Q$ (All units are in dB relative to kT_oB.)

P_Q (see eq (8) in the text) $= 60.3 - 27.3 \log_{10} f_{MHz}$

= 33.0 dB above kT_0B for 10 MHz.

Thus

$$F = 33.0 + [(6) - (+10.3)]$$

= 28.7 dB, the noise figure of the Marconi antenna at 10 MHz.

This result is identical to that obtained by method 1, which used the gain definition, $g = A_{e_{aa}}/A_{e_m}$.

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